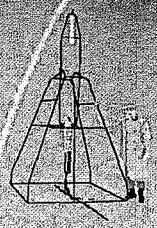
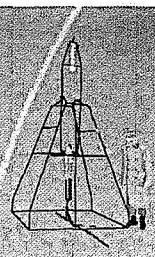


X-ray Polarimetry with a Micro-Pattern Gas Detector

Joe Hill

Exploration of the Universe Division

NASA/Goddard Space Flight Center

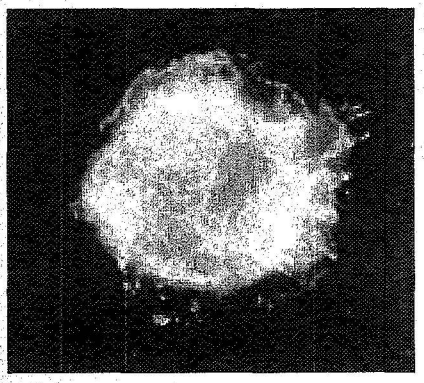


Overview

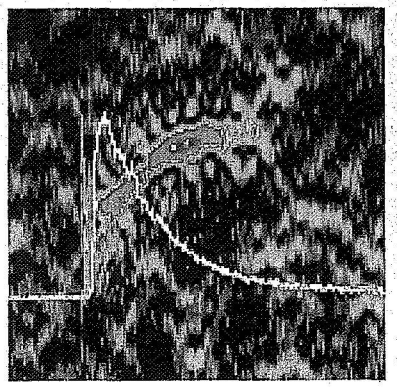
- Science Drivers for X-ray Polarimetry
- Previous X-ray Polarimeter Designs
- The Photoelectric Effect and Imaging Tracks
- Micro-pattern Gas Polarimeter Design Concept
- Preliminary Results
- Plans for the Future

The Missing Link?

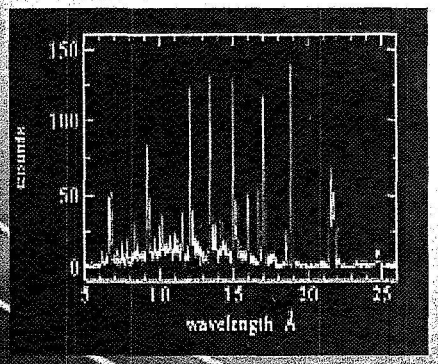
Imaging: Chandra



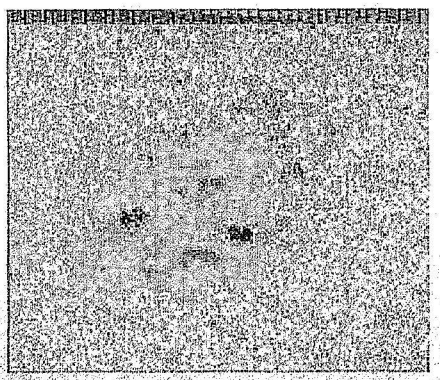
Timing: RXTE

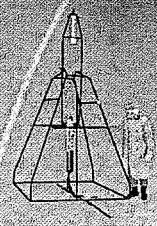


Spectroscopy: XMM
Chandra, Con-X



Polarimetry?



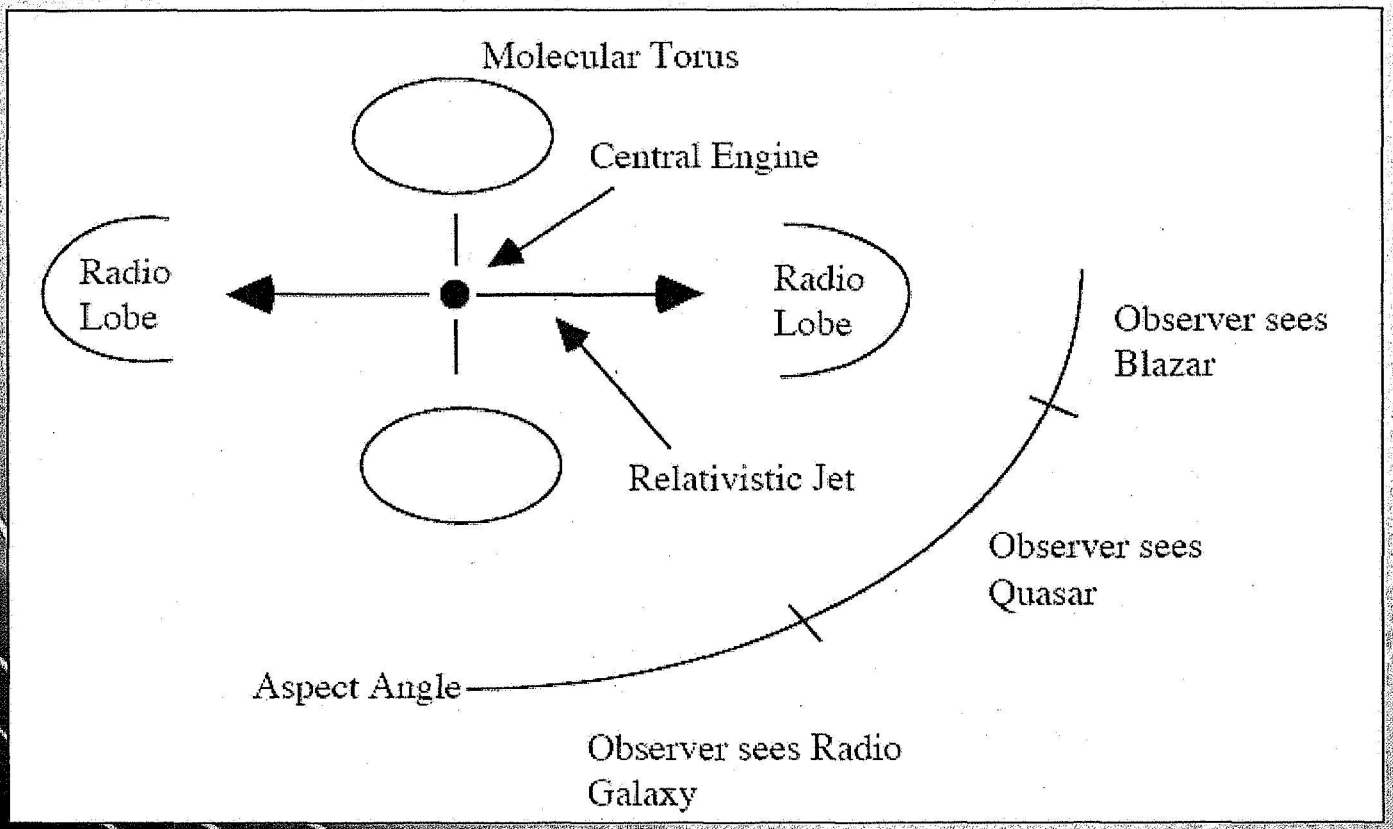


Science Drivers

- How important is particle acceleration in supernova remnants?
- How is energy extracted from gas flowing into Black holes?
- What happens to gas near accreting Neutron Stars?

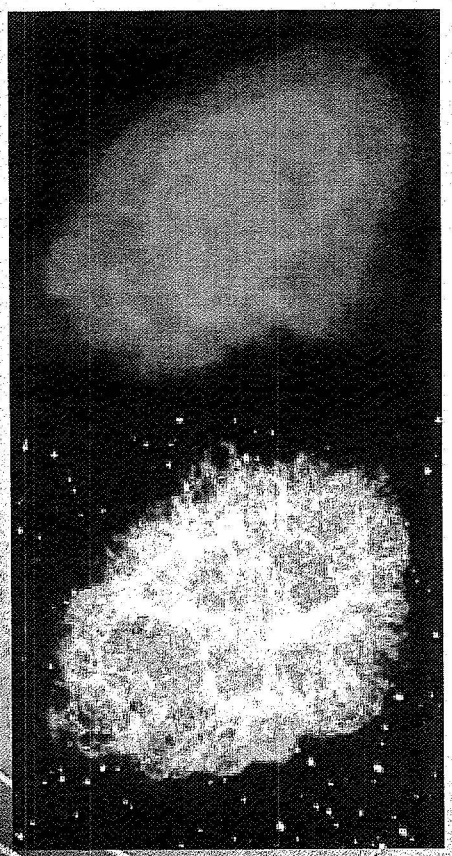
The degree, direction and energy dependence of the polarisation provides a measure of the non-thermal electron distribution and possible magnetic field configurations

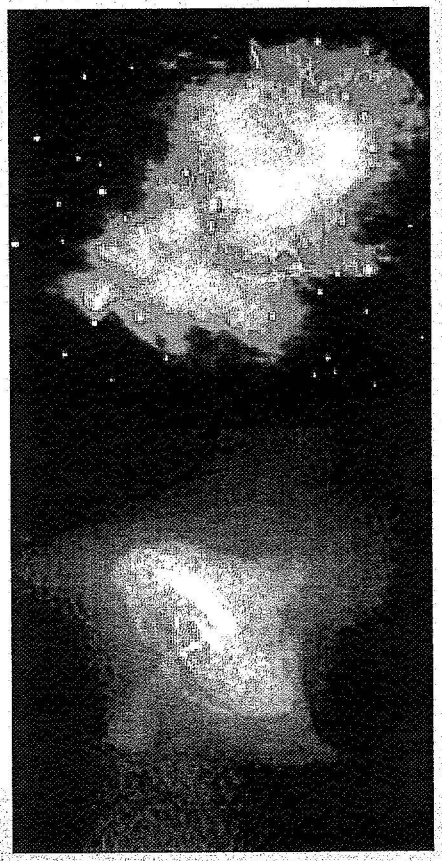
Unified Theory?



The Crab Nebula

Radio:
VLA





Infra-red:
Keck

Optical:
Palomar

X-ray:
Chandra

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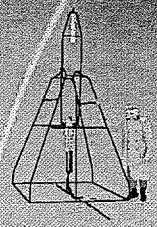


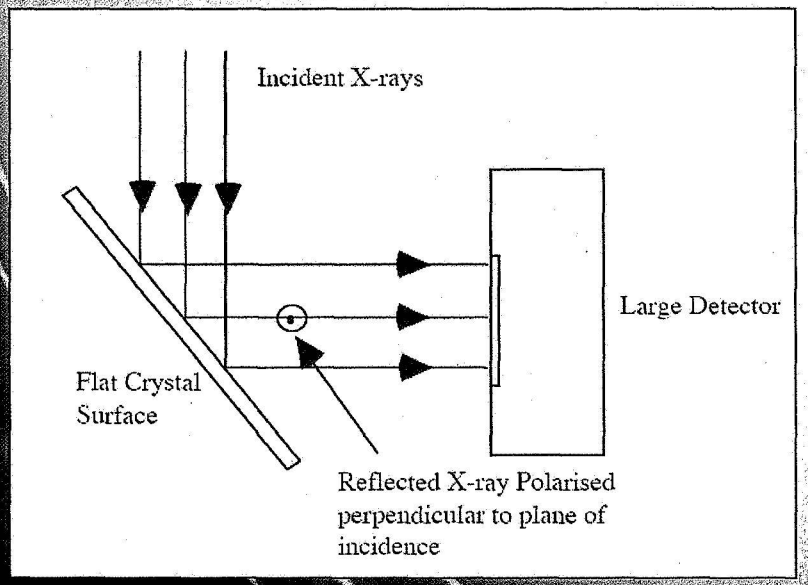
Potential Sources

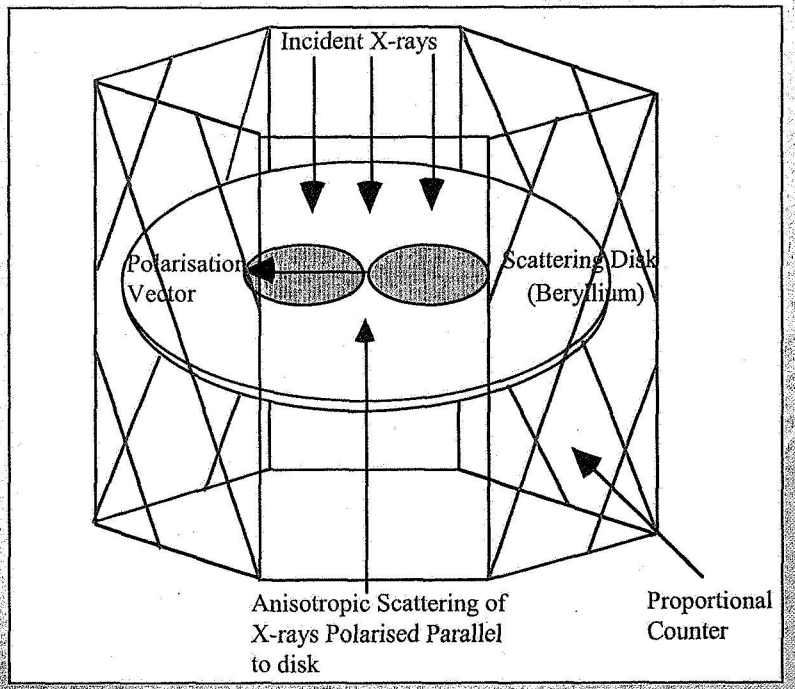
- Sources bright enough for a rocket flight observation in yellow

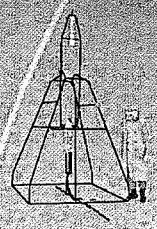
ROSAT Source Name	SIMBAD or Common Name	Measured by OSO 8		Source FOM =cnts*hr2	Source Type
1RXS J170248.5-484719	4U 1658-48 (V* V821 Ara)	X	100.0	229.6	Low Mass X-ray Binary
1RXS J214429.0+381913	Cyg X-2	X	1.0	130.1	Low Mass X-ray Binary
1RXS J053431.2+220218	Crab	X	19.2	100.7	SNR Pulsar
1RXS J173143.6-165736	4U 1728-16 (V2216 Oph) (Oph X-1)			85.3	Low Mass X-ray Binary
1RXS J170544.6-362527	Sco X-2	X	22.0	78.0	Low Mass X-ray Binary
1RXS J182340.5-302137	4U 1820-30 (SGR X-4)	X	10.8	66.0	Low Mass X-ray Binary
1RXS J152040.8-571007	Cir X-1			60.5	Low Mass X-ray Binary
1RXS J183956.9+050203	Ser X-1	X	64.8	48.7	Low Mass X-ray Binary
1RXS J195821.9+351156	Cyg X-1	X	2.4	41.0	High Mass X-ray Binary
1RXS J232325.4+584838	CAS-A (SNR111.7-02.1)	X	100.0	39.7	Super Nova Remnant
1RXS J173858.1-442659	4U 1735-444 (V926 Sco)			36.5	Low Mass X-ray Binary
1RXS J180132.3-203132	SGR X-3			29.7	Low Mass X-ray Binary
1RXS J173602.0-272541	1RXS etc			25.9	Low Mass X-ray Binary
1RXS J181601.2-140213	V* NP SER			24.1	Low Mass X-ray Binary
1RXS J164055.5-534505	4U 1636-53	X	60.1	23.0	Burster

X-ray Polarimeters

- Bragg Crystal
- Thomson Polarimeter



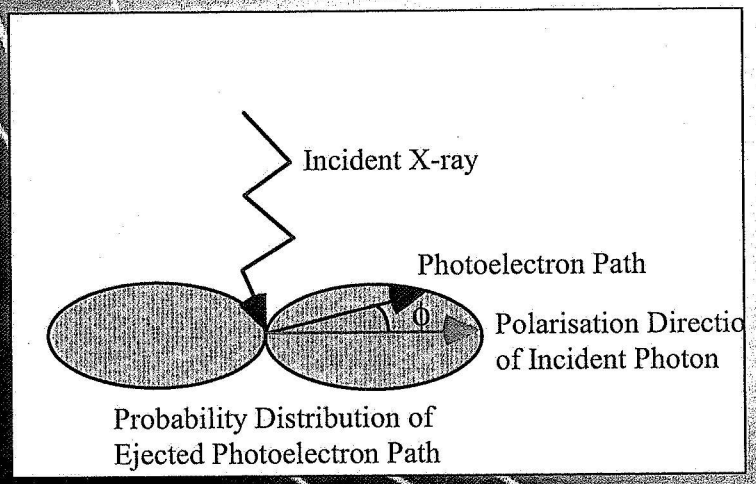


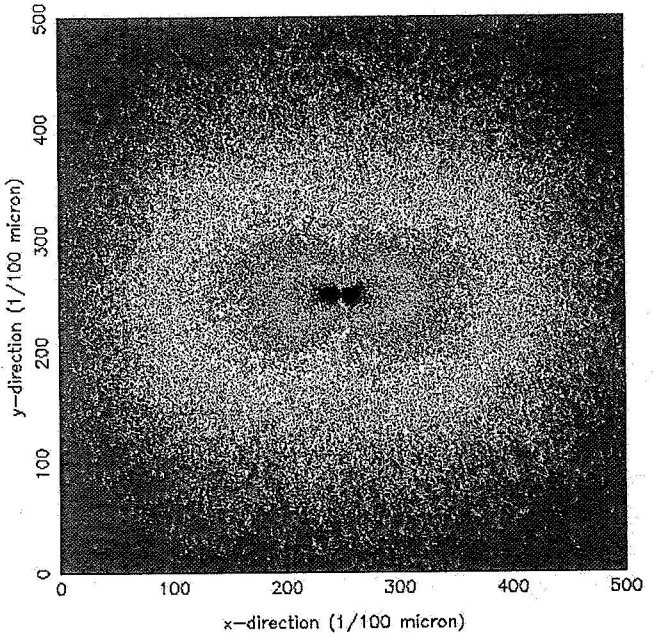


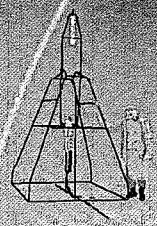
The Photoelectric Effect

- The photoelectron is ejected with a $\cos^2\theta\sin^2\phi$ distribution aligned with the E-field of the incident X-ray
- The photoelectron looses its energy with elastic and inelastic collisions creating small charge clouds

$$P(\varphi)d\varphi = \cos^2\varphi d\varphi$$







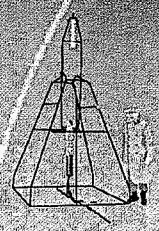
Photoelectron Emission Angle

- Direction of the major axis of the second moment, M, of the charge distribution:

$$X_{rms} = \sqrt{\frac{\sum_{ij} E_{ij} i^2}{\sum_{ij} E_{ij}} - \left(\frac{\sum_{ij} E_{ij} i}{\sum_{ij} E_{ij}}\right)^2} \qquad Y_{rms} = \sqrt{\frac{\sum_{ij} E_{ij} j^2}{\sum_{ij} E_{ij}} - \left(\frac{\sum_{ij} E_{ij} j}{\sum_{ij} E_{ij}}\right)^2}$$

$$\langle XY \rangle_{rms} = \frac{\sum_{ij} E_{ij} ij}{\sum_{ij} E_{ij}} - \left(\frac{\sum_{ij} E_{ij} i}{\sum_{ij} E_{ij}}\right)\left(\frac{\sum_{ij} E_{ij} j}{\sum_{ij} E_{ij}}\right) \qquad \phi = \frac{1}{2}\tan^{-1}\left(\frac{-2\langle XY \rangle_{rms}}{Y_{rms}^{\ 2} - X_{rms}^{\ 2}}\right)$$

$$M = \sum_{ij} E_{ij} \times (X_{rms} \cos^2 \phi + Y_{rms} \sin^2 \phi + 2\langle XY \rangle_{rms} \cos\phi \sin\phi)$$



Modulation Factor

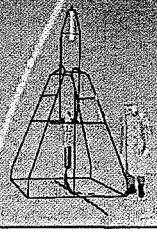
- Fit function to the angular distribution

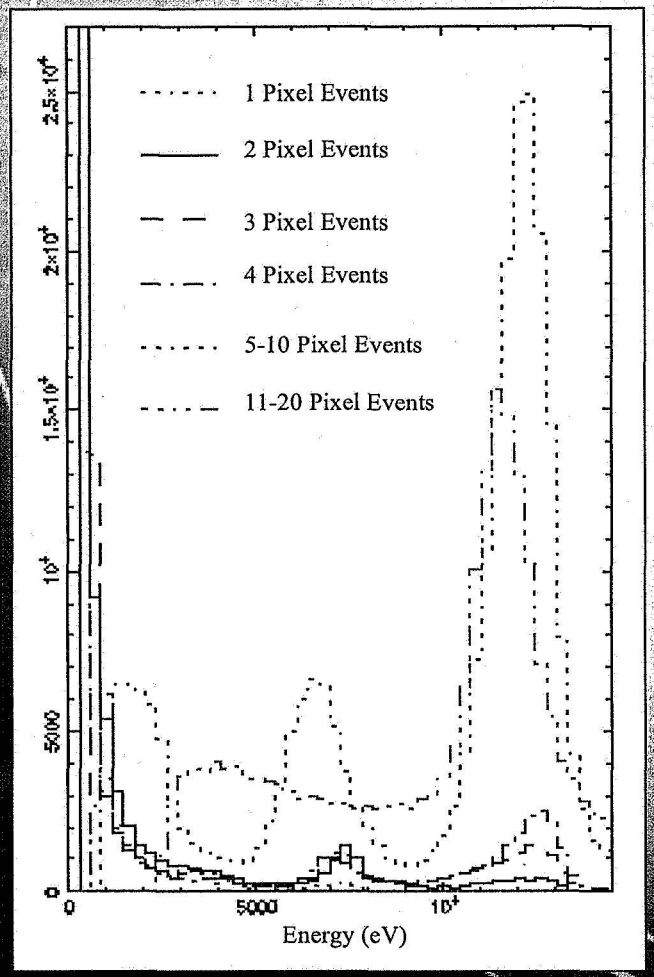
$$N(\phi) = A + B\cos^2(\phi + \phi_{pol})$$

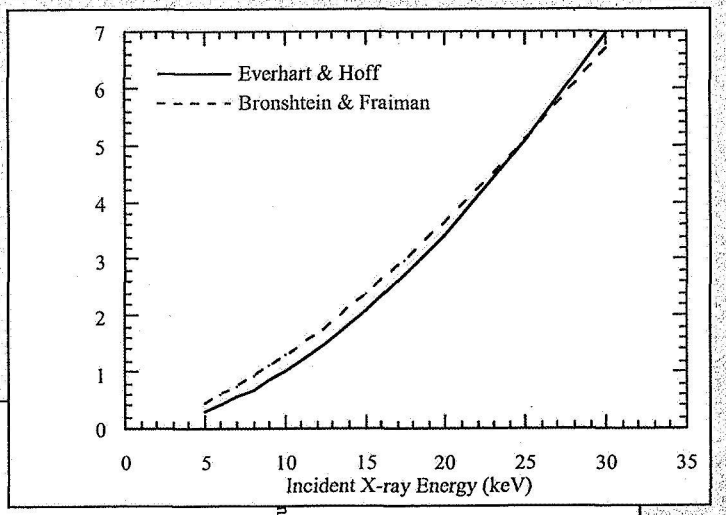
- Polarisation Sensitivity or Modulation Factor, μ:

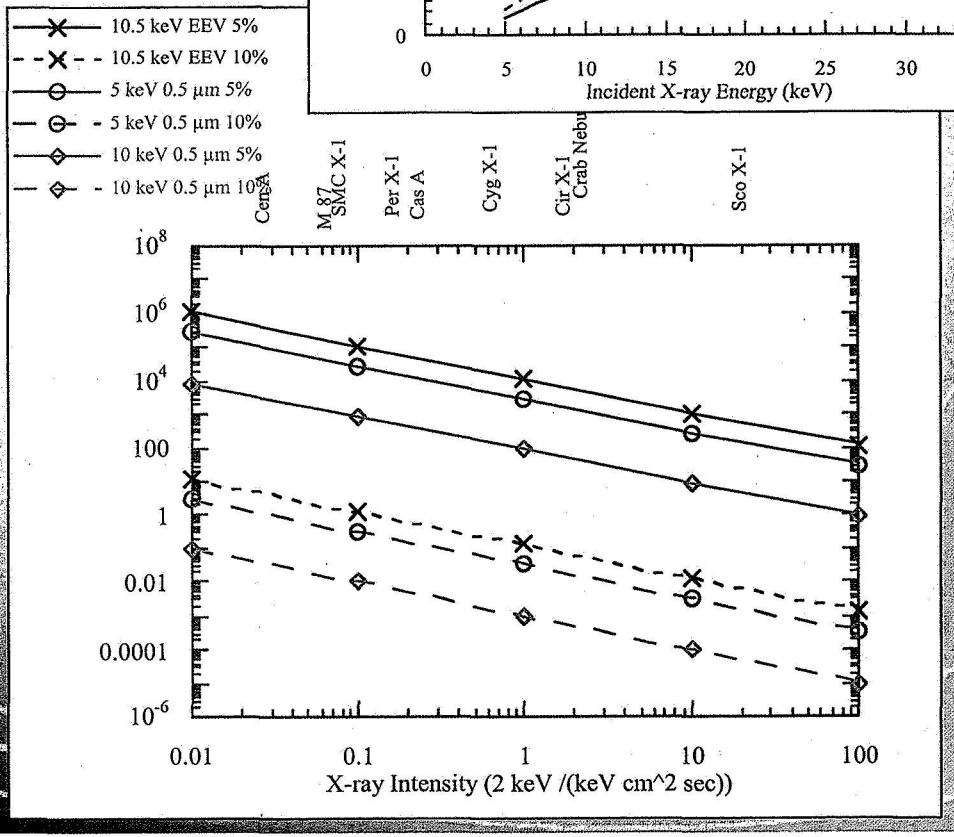
$$\mu = \frac{N_{\max} - N_{\min}}{N_{\max} + N_{\min}} = \frac{B}{2A + B}$$

Small Pixel CCD Polarimeters









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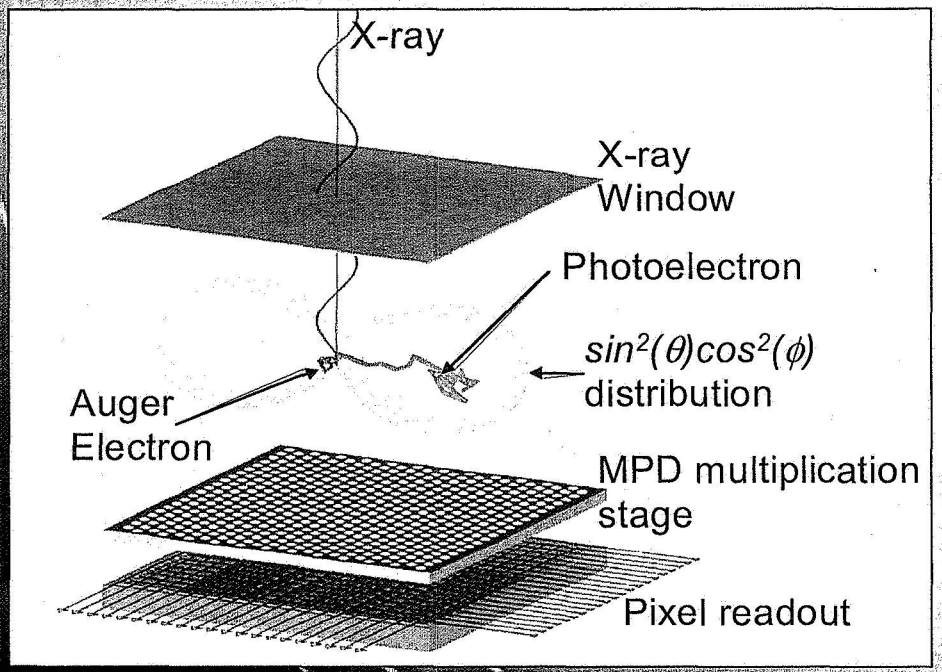
Micro-Pattern Gas Polarimeter

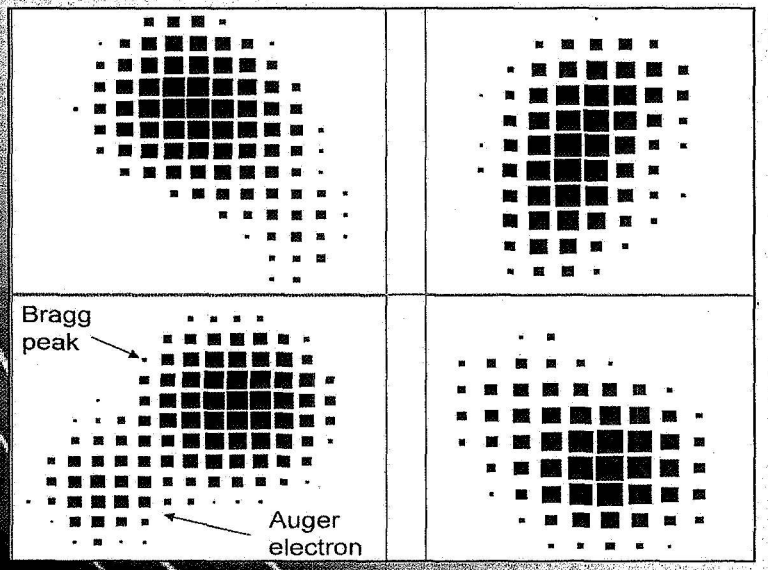


- X-ray interacts in the gas
- Photoelectron creates electron cloud
- Electron cloud drifts to cathode
- Electron multiplication occurs between cathode and anode
- Charge finally collected at the pixel readout

Initial Results

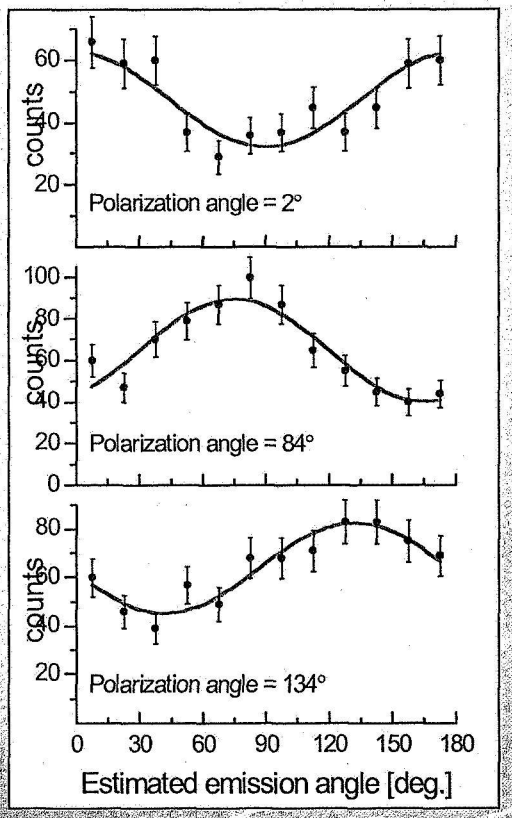
Track images in Neon:

6 keV **4.5 keV**

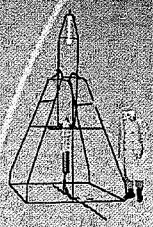


At 4.5 keV μ=30%

Histograms of emission angles from reconstructed 4.5 keV events



(Black et al. 2001)



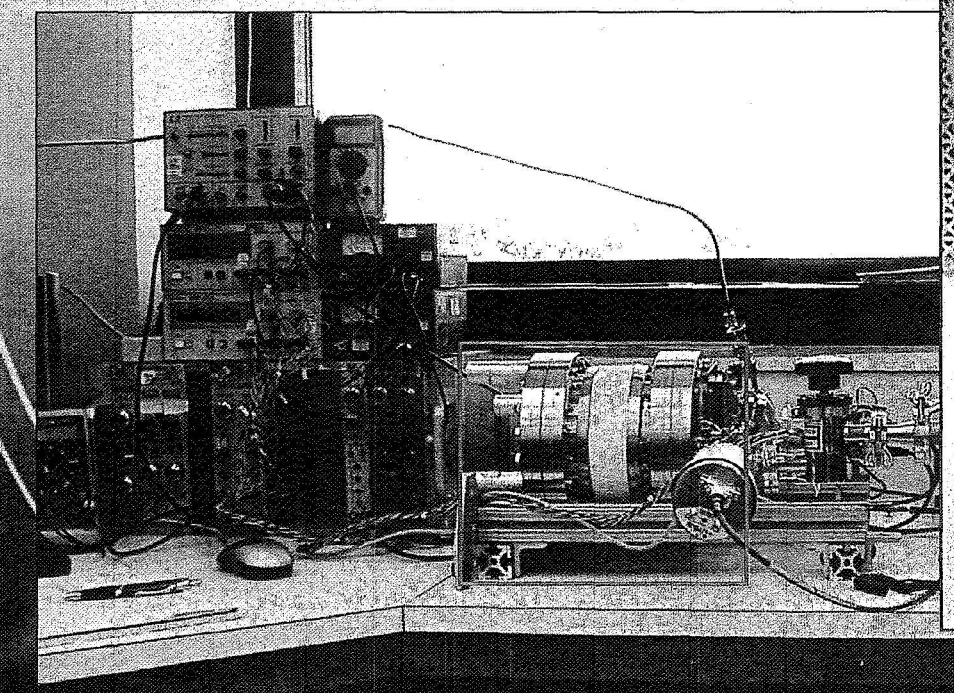
Further Development

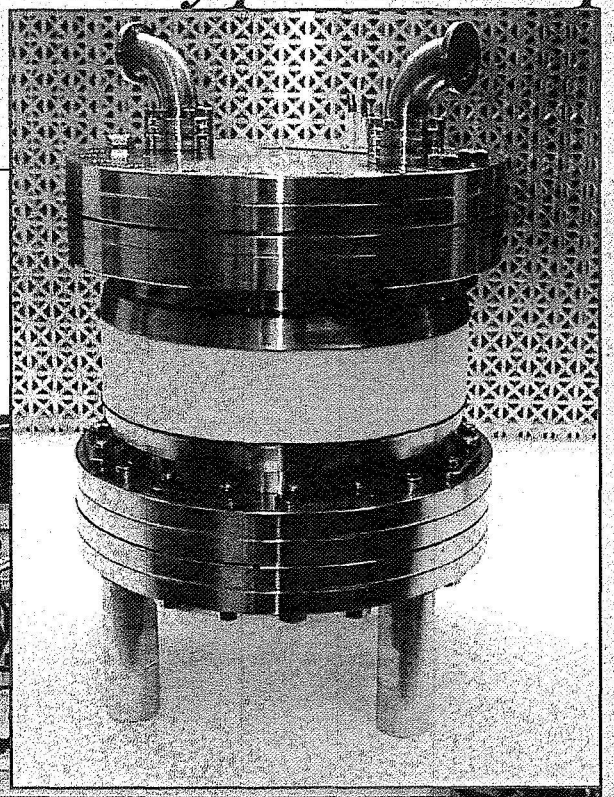
- Based on this promising result continued development to build a flight prototype
- Improve on the previous measurements by using an ASIC with hex pixels for the readout

$$FOM = QE^{-1/2}\Delta E^{-1/2}\mu^{-1}$$

Type of Polarimeter	Modulation Factor (%)	Quantum Efficiency (%)	Characteristic Bandwidth (keV)	Figure of Merit
Bragg Crystal Thomson Polarimeters	96	99	0.22	2.3
OSO-8	28	30	10	2.1
SXRP	71	5.4	10	1.9
CCD Polarimeter				
12 x 12 μm (exp)	3	3	25	38
4 x 4 μm (mod)	16	3	25	7.2
4 x 9 μm (exp)	18.5	41	12.5	2.4
0.5 x 0.5 μm (mod)	16.5	50	15	2.2
Micro-pattern gas Proportional Counter	30	30	4	3.0

The proto-type set-up





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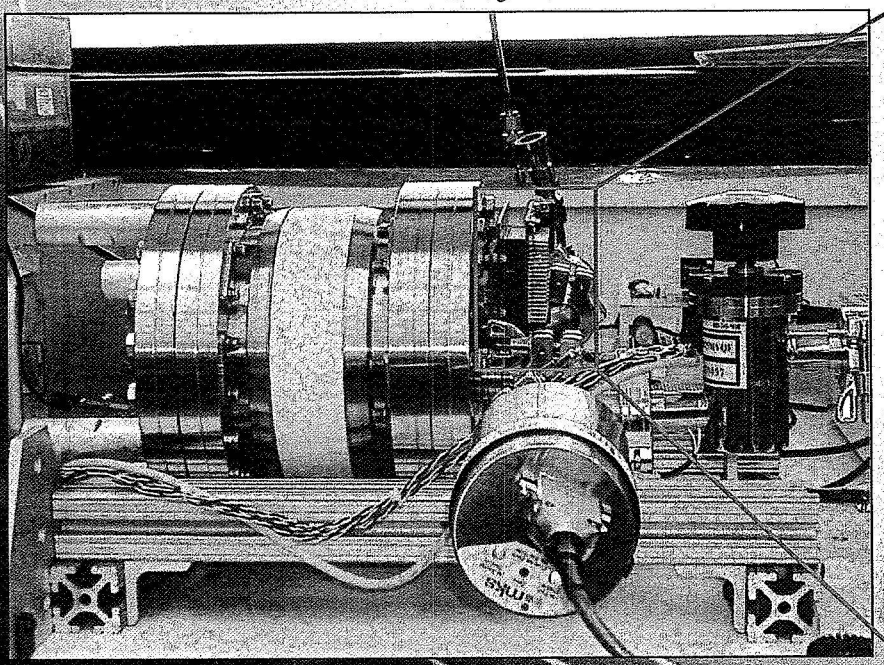
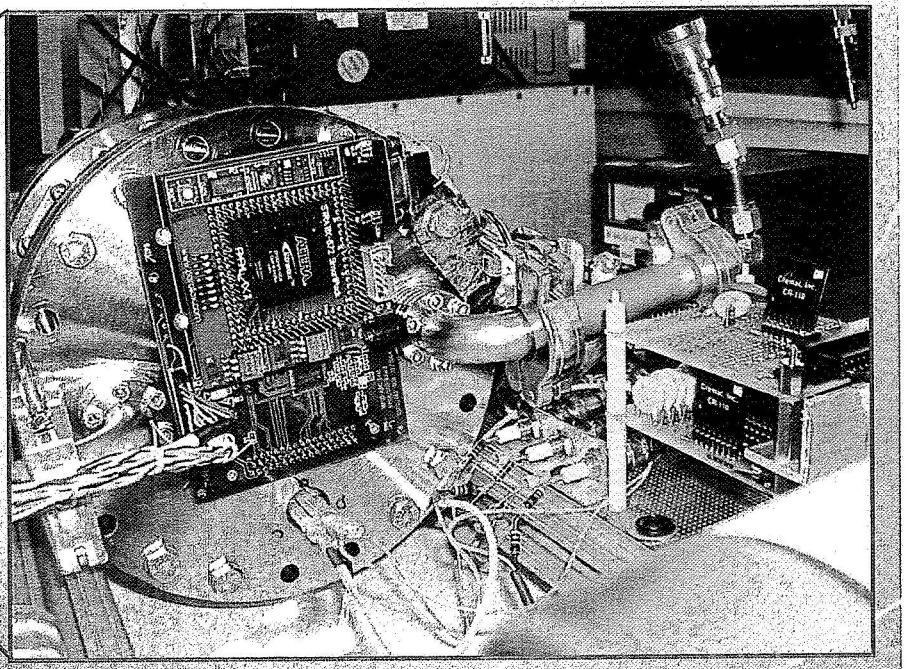
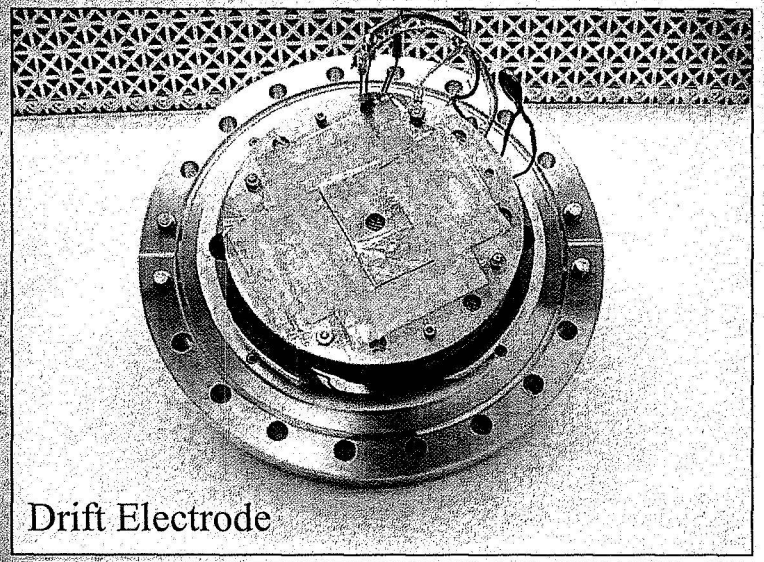
Readout Electronics

- An FPGA controls the ASIC and the ADC
- Allows a programmable window mode - preserves telemetry
- Real-time pedestal subtraction (bias subtraction)
- Event-by-event centroid calculation

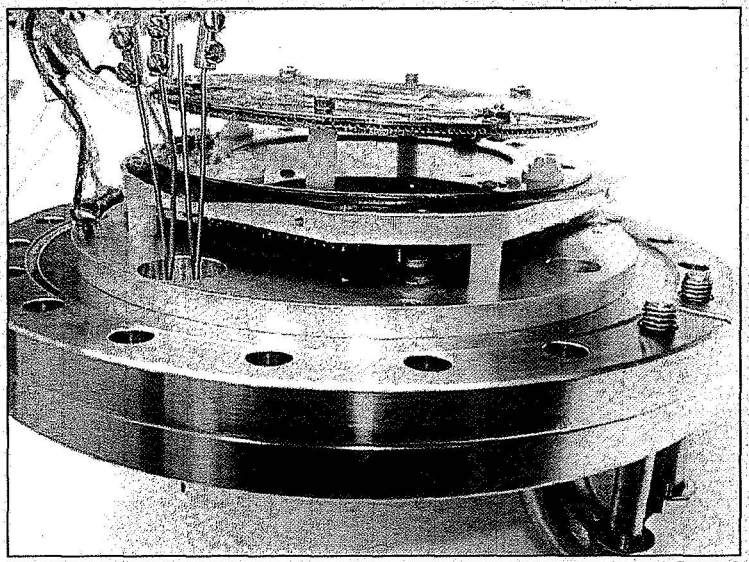


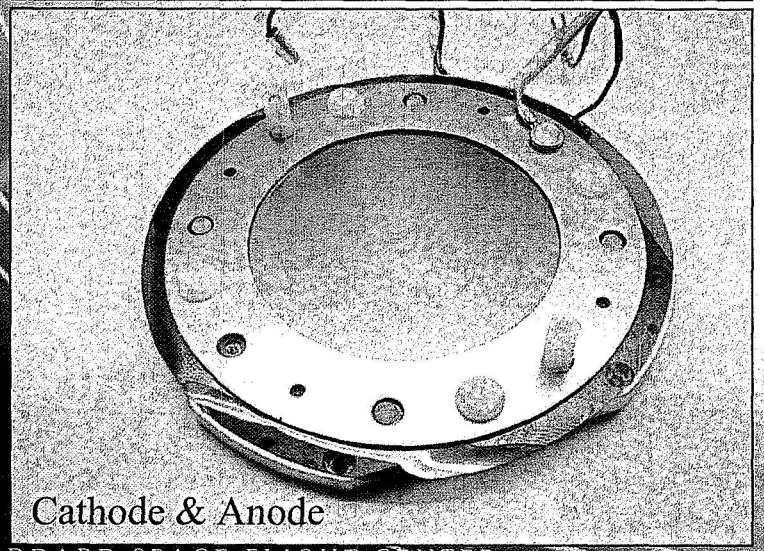


Detector set-up

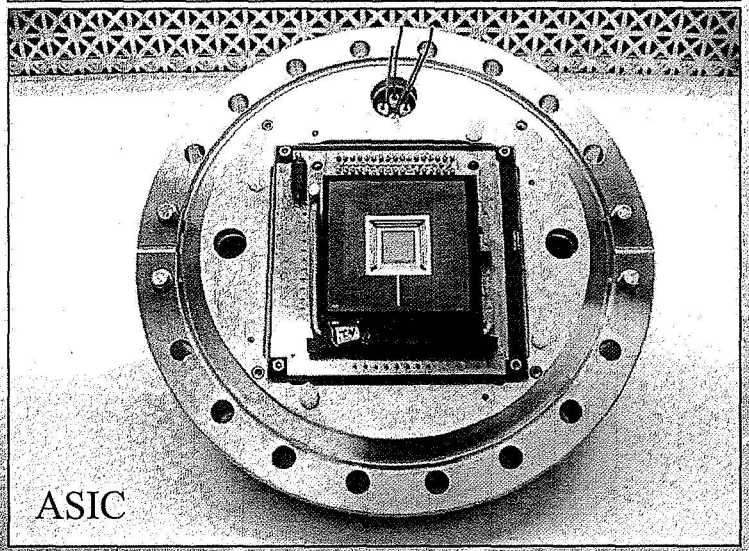


Drift Electrode





Cathode & Anode



ASIC

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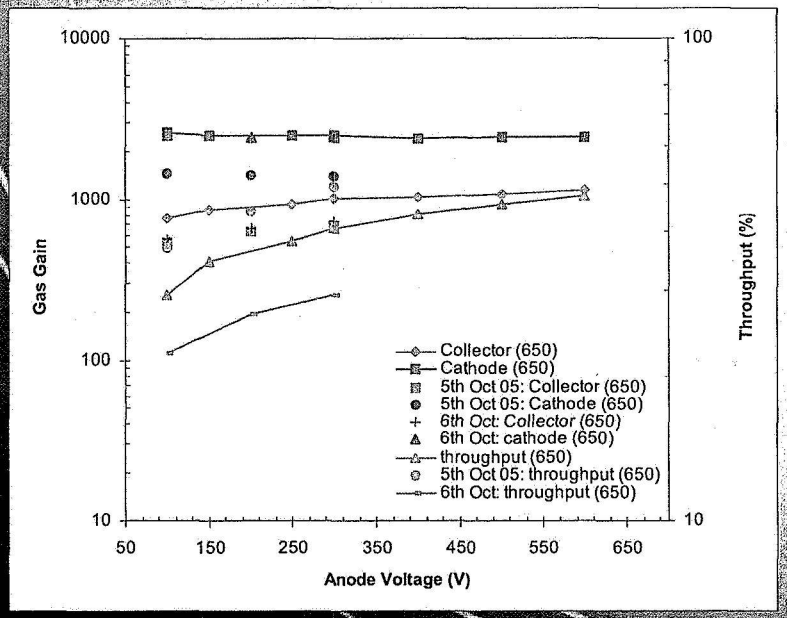
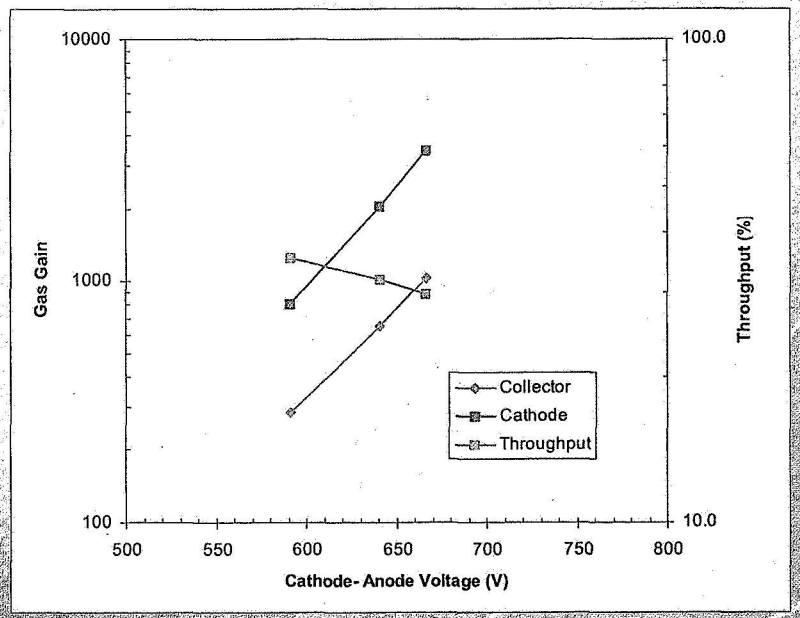
Detector Optimisation

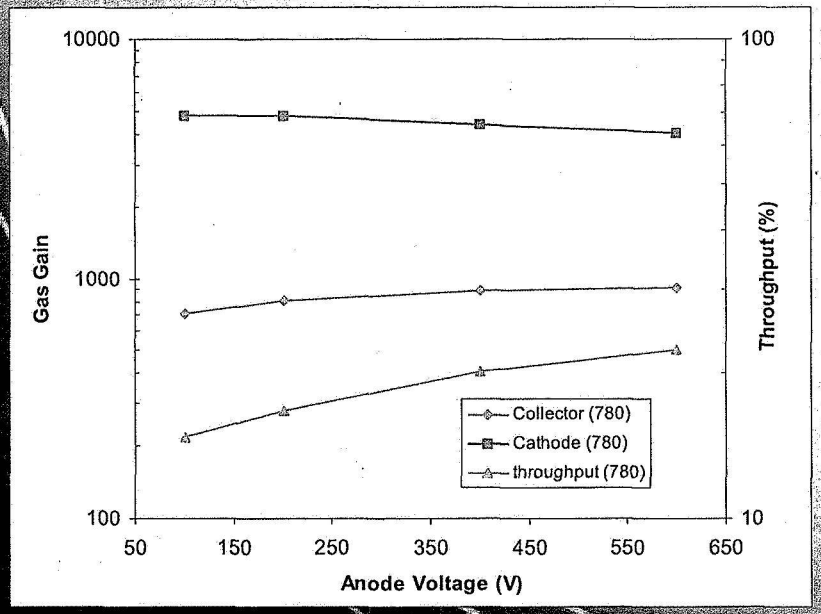
- 150 μm meshes:120 μm separation
- 200 Torr of CO_2
- Anode 1 mm from Cu collector

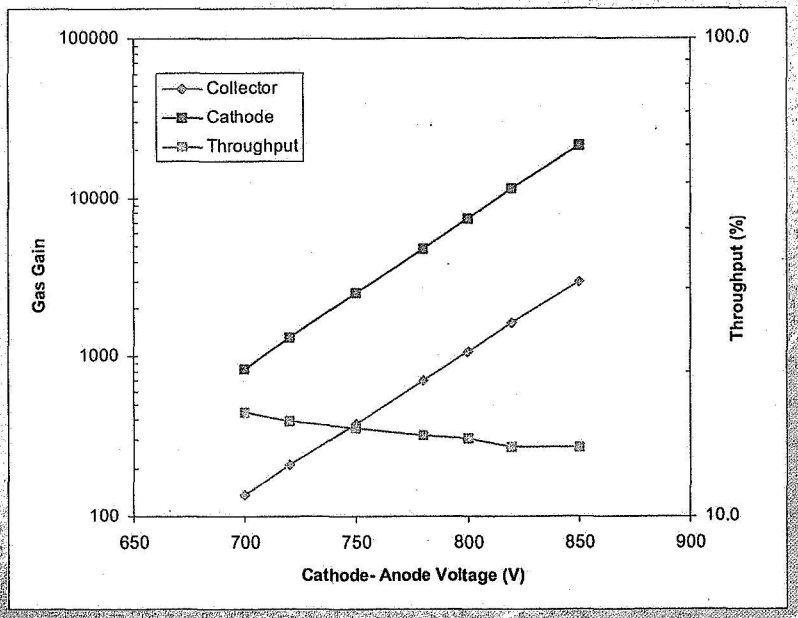




Detector Optimisation

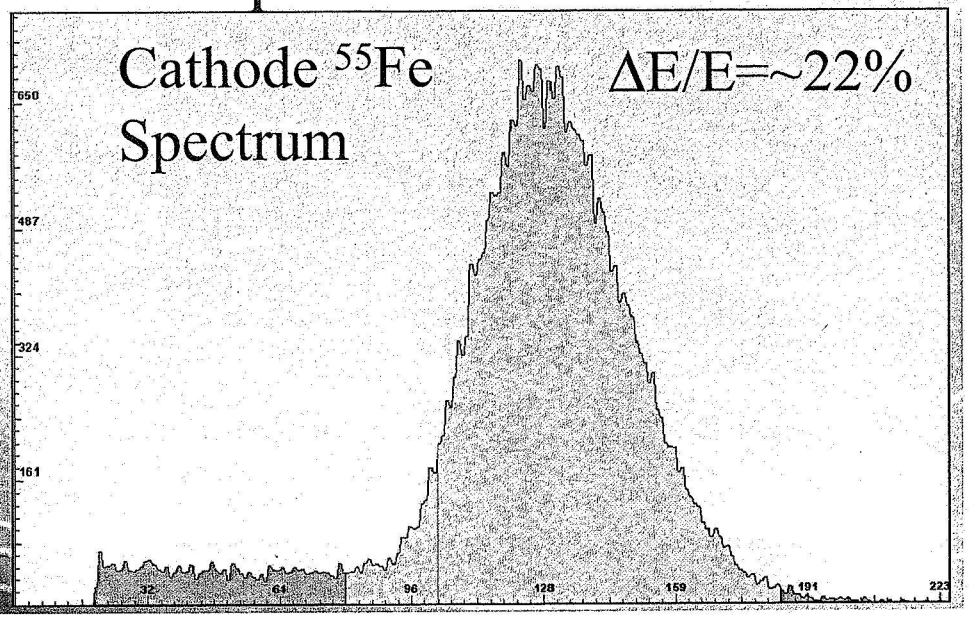
- 150 μm meshes:180 μm separation
- 200 Torr of CO_2
- Anode 1 mm from Cu collector





Mesh Configuration

- Decreasing spacing yields greater throughput to collector
- Spacing too narrow => HV breakdown in the multiplication region at low gain
- 150 μm separation is ~ optimum



Preliminary ASIC Tests

- 80 μm pitch ASIC (building 50 μm pitch)
- Substitute ASIC in place of Cu plate
- 150 μm pitch meshes at 180 μm separation

Un-polarised ^{55}Fe X-rays

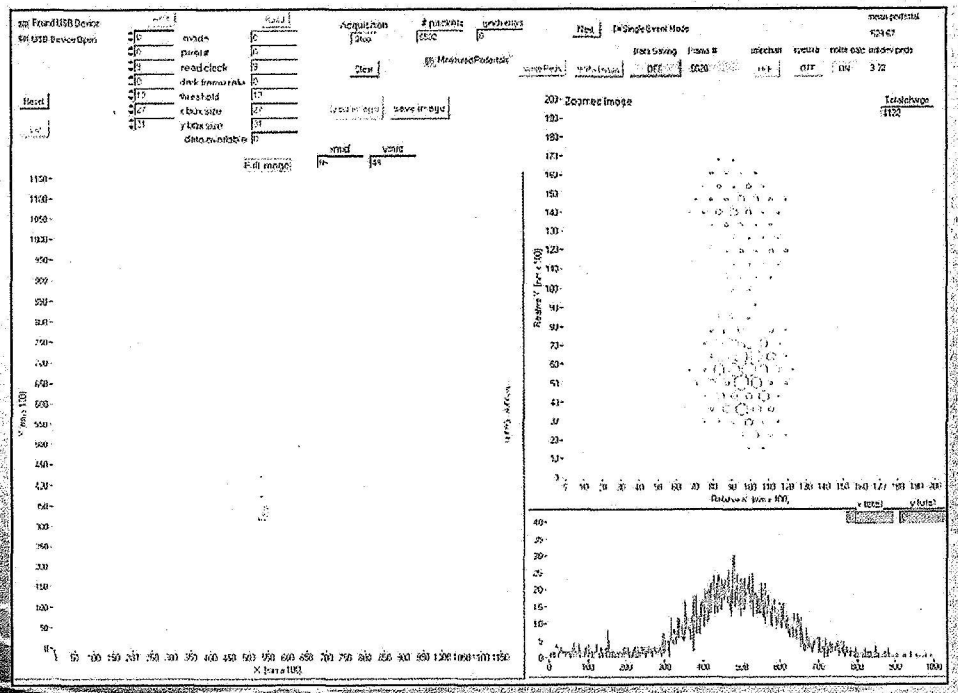
355 Torr of CO_2

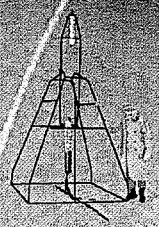
Drift 1.84 kV

Cathode 1.48 kV

Anode 500 V

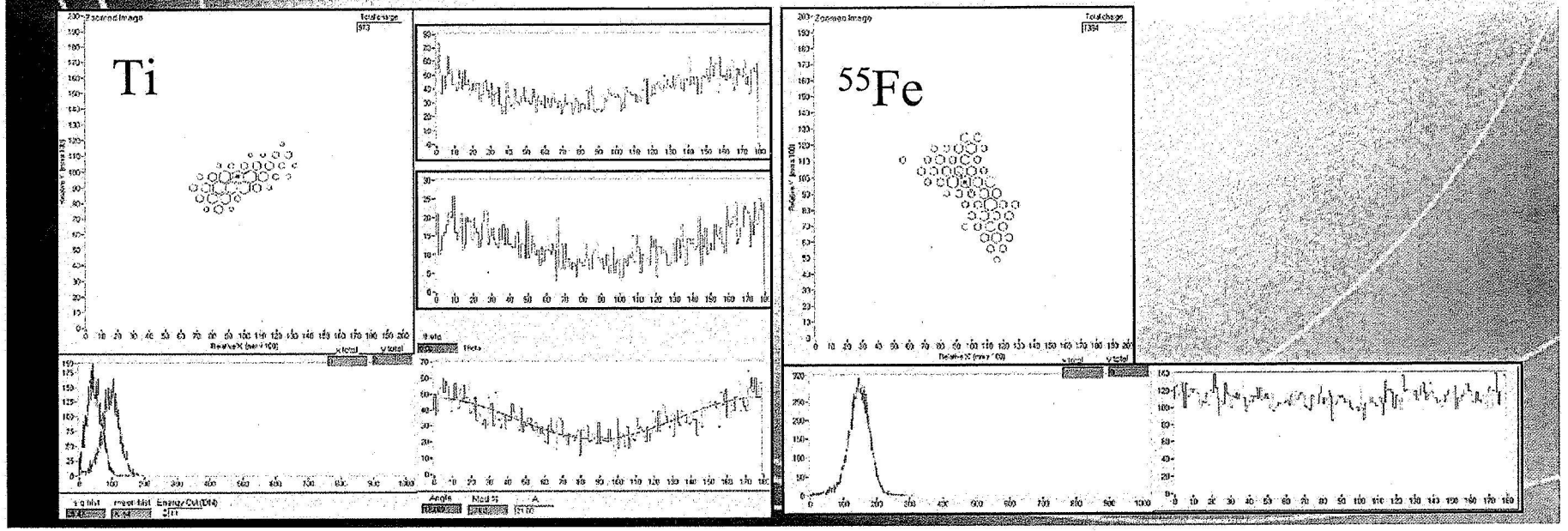
ASIC Vdd=2.82 V

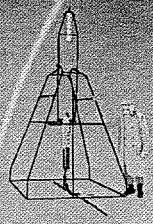




(Very) Preliminary Results

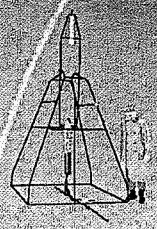
- Optimising the event analysis software
  - Discard edge events
  - Discard low energy events
- Tests with unpolarised ^{55}Fe, 0 degrees and 320 degree polarised Titanium X-rays





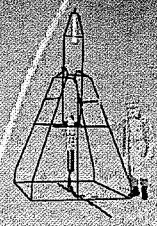
Further Work

- Determine modulation factor for current configuration
- Verify results against the simulator
- For a given energy band
  - Characterise different gases
  - Optimise pressure
- Optimise voltages for resolution and sensitivity
- Test meshes with 80 μm pitch
- Characterise ASIC operation
- Quantify Quantum Efficiency for optimum polarization sensitivity



Future Plans

- Operate detector at mirror focus
- Secure a funding opportunity to prove the concept
  - Sounding Rocket: 15 mins, 0.6-6 keV
  - Balloon: 20 hrs, 30-50 keV
  - SMEX or MIDEX



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